AN INVESTIGATION OF THE EFFECTS OF COMPUTER

GRAPHICS ON EXECUTIVE DECISION MAKING

IN AN INVENTORY CONTROL ENVIRONMENT

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by

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PREFACE

The central question of this dissertation is
whether an objective ranking of utility to the decision
maker can be assigned to the form of the presentation to
him. In this instance we are interested in whether an
executive decision can be reached earlier, faster or more
consistently with a computer-driven display device than with
the more customary printed material.

An experimental group of eighteen management-level
subjects with extensive experience in inventory control
was assembled for a two-week short course in advanced
inventory management techniques. During the short course,
the subjects were exposed to simulated results from
computer application of certain inventory control policies
to a hypothetical inventory system handling $\underline{n}$ items. This
system is faced with a certain randomly derived set of
orders, price changes, replenishments of stock and other
transactions. The results of the simulation were presented
on both printer paper and on a cathode ray tube display
device. For each method of presentation, results were
represented in both tabular and graphical form.

When a substantial part of the course had tran-
spired, the subjects were asked to evaluate the results of
simulating two inventory systems, using printer output for

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one evaluation and the cathode ray tube display device for
the other evaluation. By means of a Latin square design
and rank order statistics these evaluations were inspected
to determine if experienced decision-makers using a display
device could reach a decision that was earlier, faster or
more consistent than a decision reached by means of printer
output.

The results indicated, with very high statistical
significance, that a decision could be made faster with a
display device, and with high significance that a decision
could be made on the basis of less information by
means of the display device. Other results pointed to
decisions that were more consistent for the individual and
which tended more to agree with the rest of the group when
display device techniques were used for the evaluation of
the inventory systems.

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I. INTRODUCTION

The central question of this dissertation is whether an objective ranking of utility to the decision maker can be assigned to the form of the presentation to him. In this instance we are comparing the utility of a cathode ray tube display to printed material, and are interested in whether an executive decision can be reached earlier, faster, or more consistently with the display device than with the more customary printed material.

In order to provide a vehicle for the experiment, and to establish an environment for a discussion of the results, a simulator was written for computer application of certain inventory control policies to a hypothetical inventory system handling $\underline{n}$ line items. This system is faced with a certain randomly derived set of orders, price changes, replenishments of stock, and other transactions. This simulator is governed by a number of pseudo-random variate generators and by program constants. These parameters are set by the user. An important set of these parameters establishes the management <u>policy</u> for inventory control. A <u>policy</u> is formalized by the selection of a combination of three policy components from among:

1. Two service rules to be used in variable safety level computation.

2. Two smoothing constants to be used in demand
forecasting by exponential smoothing.

3. Three purchase quantity computation rules.
A Cartesian product of these three sets gives a total of
twelve inventory control policies to be investigated. The
simulator exercises each of the twelve policies for a
period of twenty-four months of generated transactions.
At the end of each of the simulation months, relevant
statistics are gathered about the system performance under
each policy set. In order to insure uniform interpretation
of the statistics, each policy set is exercised under
identical _initial_ conditions.

Due to the large number of parameters which are
available to the user, the simulation program provides a
versatile vehicle for this investigation. The statistics
which the program develops are quite extensive, and only
part of these data are used in the investigation. Although
the simulation program and its results are of interest in
their own right, the present investigation uses the simu-
lator as a vehicle rather than the object of investigation.

Based on the data presented to him by the simulation
program, the decision maker is expected to make a series of
decisions. At the end of each simulation month, he ranks
the policies in the order of acceptability to him. Each
decision maker thus produces a set of twenty-four ordered
lists of twelve policies each, from which conclusions will
be drawn concerning the form of presentation of the data.

The experiment was conducted in the context of a short course in advanced inventory control techniques. A class of eighteen interested and experienced people in the inventory control field met for two weeks during August 1968, for twenty class hours of instruction under the auspices of the Department of Computer and Information Science at the University of North Carolina in Chapel Hill. During the course the following topics, among others, were treated:

1. Exponential and weighted time series smoothing for demand forecasting.

2. Probability distributions of demand.

3. Evaluation of order-quantity computations.

4. Variable safety level concepts.

5. Performance budgeting.

6. Master record file design.

Near the end of the course, each participant was given, as examination problems, the statistics resulting from two different simulation runs. The participants were asked to rank the various management policies, month by month and to make other decisions regarding the policies, on the basis of the data presented. Each participant acting in the capacity of decision maker, or decider, using both printer output on one problem and graphic display presentation on the other, demonstrated his decision making ability.

The statistics from the simulation program were

displayed in a variety of formats on standard computer
printer paper. The statistics included such data as
percent availability of stock, number of purchase orders
generated, lost sales and total dollar investment in
inventory. The output was in the form of tabular listings
and bar graphs. Also, for each problem, the IBM 2250
cathode ray tube display unit was programmed to show the
same data as appear on the printer output, in fundamentally
the same listing and graphical formats. Thus the exper-
iment did not attempt to establish the relative effective-
ness of listed versus plotted data. Instead it investi-
gated the relative effectiveness of printed versus display
presentation of such data. The display unit was under the
control of the decider, who was able to specify which of
the twenty-four months and the title of the displayed data
which he wanted to see. In both display and printer output
cases, he was expected to start at the first month and
proceed through the months in order.

The course participants were divided into two test
groups, each group consisting of nine individuals chosen
at random. Tests were made in regard to:

1. Are decisions made faster? The elapsed clock
   time to decide on a ranking of policies which
   the decider would be willing to commit himself
   to for future action was tested.

2. Are decisions made earlier? The calendar month
   (out of the twenty-four months of simulation)

in which the decider feels he has enough data
to commit himself to a ranking for future action
was tested.

3. Are decisions made faster? The elapsed clock
time to complete the remainder of the problem
was tested. After committing himself to a
ranking, the participant continued the problem
through the twenty-fourth month.

4. Are decisions made more consistently? Individ-
ual correlation coefficients from the Spearman
rank correlation test were computed.

5. To what degree do the members of each group
agree among themselves in regard to the
rankings? Kendall's W coefficient of concord-
ance was computed for each cell of the Latin
square.

In summary, the decider makes two basic kinds of
decisions. He decides on a ranking at each month in turn,
and he decides whether or not to indicate at this month
that he feels confident enough of his ranking to predict
that it will not significantly change over the remainder
of the twenty-four months.

The resulting ordered lists of policy sets and the
preparation times were analyzed in two basic ways. First,
a 2 x 2 Latin square design with repeated measures was
used in an analysis of variance. Rank order statistics
were then used to test the consistency of each individual

decision maker and the concordance of a group of decision makers.

The statistical analysis of variance explored the differences between graphic and printed data presentation (treatment), between the first and second problems done by each participant (order), and isolated the differences between the performance of Group I and Group II.

The rank order of the policy sets at the decision month and at the end of the twenty-four month simulation was compared by the Spearman rank correlation coefficient test for each participant. These rank correlation coefficients were then arranged in the Latin square and an analysis of variance was performed. These tests determined whether treatment, order, or group composition caused differences in the consistency of a participant's final answer, after he had full data available, with that at the month of commitment to a policy ranking. A Kendall's coefficient of concordance was computed to measure how well the rankings produced by each test group on each problem at the decision month agreed among themselves.

II. THE SIMULATION MODEL

This simulation program is a dynamic model of a
general inventory control situation, and is intended to
investigate inventory management policies in regard to
forecasting, purchase quantity computation and service
level over a range of items whose characteristics are
defined by the user. The model was programmed in PL/I
utilizing the IBM System 360 Model 75 at the Triangle
Universities Computation Center, Research Triangle Park,
North Carolina.

The model establishes identical initial conditions
for each of the twelve policies and then generates a
series of actions which represent daily business trans-
actions under a particular policy. This series of daily
actions is continued over a simulation cycle of two
360-day years for each policy in question. Reports are
generated after each thirty-day month of simulation.

The Cartesian product of the sets of decision
rules for service level (two rules), purchase quantity
computation (three rules), and forecasting methods (two
rules), gives twelve distinct cycles of 720 simulation
days each.

The following are the formal properties of the
simulation model. While the program is well documented

in the program listing, the tabulation below of the more
important elements defines the model by a categorization
appropriate to the simulation of economic systems.[1] We
will define exogenous variables as those independent
parameters which are treated by the system as inputs.
They will, in general, be stochastic variables which are
generated internally by the program's random variate
generators. Status variables will describe the state of
the system in relation to an appropriate time period, and
are generally found to be in a feedback loop which inter-
acts with the exogenous variables of a preceding time
period. For instance, the on-hand inventory level, ONH,
reflects a status at any one point in time, but is
dependent on the values of several stochastic variables in
preceding time periods. Endogenous variables will be the
output result of interactions between exogenous and status
variables. These are the numerical results which are
found on the printed and cathode ray tube display output.
Where status variables describe the system and interact
with other variables, endogenous variables are collection
points for output purposes only, and do not interact with
other variables to affect system performance. Identities
will be either definitions or tautologies which describe
model components. For example, the status variable ONH

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[1]Thomas H. Naylor, et al., Computer Simulation
Techniques (New York: John Wiley & Sons, Inc., 1966),
pp. 9-20, 159-173.

is defined by the identity ONH = ONH - TRANS + DUIN, where
the identifier on the left at time t + 1 is replaced by the
expression on the right evaluated at time t. Parameters
are those variables which define the inventory control
policies and the distributions describing the environment
under investigation, as distinguished from the exogenous
variables that describe the particular experiences to which
the policies are subjected. These the investigator changes
in order to model his particular policies and simulated
environments. In all cases the identifier mentioned is
the one used in the PL/I program and is cross-listed in the
Program Attribute Table.

EXOGENOUS VARIABLES

Identifier	Description
RAND	A uniformly distributed random variate in the range 0 to .99.
Y	A random variate from one of the ten random variate generators.
X	A number in the range one to ten which indicates which of the ten random variate generators (see page 20) is being called.

STATUS VARIABLES

Identifier	Description
ONH	On hand inventory; in units of issue per line item.
HQTY	Amount due in from purchase action initiated by a purchase quantity computation; in units of issue per line item.

#SOLD   Total units sold the previous year; in units of issue per line item.

RET   Total units returned by customers over the simulation cycle; in units of issue per line item.

FREQ   Frequency of satisfied demand this year; in number of demands satisfied per line item.

CRIT   Reorder point (variable safety level); in units of issue per line item.

TOTD   Total demand last year; in units of issue per line item.

CDF   Count-down variable which shows the number of days until a due-in order is expected to be received for this stock number; in days.

PRD   Forecast monthly demand; in units of issue per line item.

AUF   Annual usage (sales this year); in units of issue per line item.

AND   Total demand this year; in units of issue per line item.

NFREQ   Frequency of demands which could not be filled; in number of demands per line item.

MDEM   Demand this month; in units of issue per line item.

DEMD   The demand registered against a stock number on any particular transaction; in units of issue per line item.

TRANS   The number sold to a customer as the result of a demand; in units of issue per line item.

BNPRICE   The computed cost price of on-hand inventory after receipt of due-in merchandise; in dollars per unit of issue.

NEX	The mean of the number of units returned by a customer against a stock number; in units of issue per line item.
FCST1	Forecast demand at previous time period; in units of issue per line item.
TRND	Demand trend; in units of issue per line item.
ERROR	Error in forecast of demand during last time period; in units of issue per line item.
TREND	Smoothed trend forecast; in units of issue per line item.
EXPCDMD	Expected demand after trend correction to forecast demand; in units of issue per line item.
MAD	Mean absolute deviation of true demand from expected demand; in units of issue per line item.
MRD	Maximum reasonable demand from variable safety level computations; in units of issue per line item.

ENDOGENOUS VARIABLES

Identifier	Description
AVAIL	Availability, the ratio of units of satisfied demand to units of total demand; in percent per policy.
AV$INV	Total inventory investment, the cost of the on-hand inventory plus due-in; in dollars per policy.
LOSS	Lost sales, the cost of not having stock which was demanded over the life of the simulation; in dollars per policy.
PURCH	Cumulative number of purchase actions generated; in number of purchase actions per policy.

S_CLITEM (1)	Total of items with unit price less than $25.00 and annual demand less than $100.00; in line items per policy.
S_CLITEM (2)	Total of items with unit price less than $25.00 and annual demand $\geq$ $100.00 and $\leq$ $1,000; in line items per policy.
S_CLITEM (3)	Total of items with unit price $<$ $25.00 and annual demand $>$ $1,000; in line items per policy.
S_CLITEM (4)	Total of items with unit price over $25.00; in line items per policy.
S_LNITEM (1)	Total of items with availability $<$ 70 percent; in line items per policy.
S_LNITEM (2)	Total of items with availability $\geq$ 70 percent to $<$ 75 percent; in line items per policy.
S_LNITEM (3)	Total of items with availability $\geq$ 75 percent to $<$ 80 percent; in line items per policy.
S_LNITEM (4)	Total of items with availability $\geq$ 80 percent to $<$ 85 percent; in line items per policy.
S_LNITEM (5)	Total of items with availability $\geq$ 85 percent to $<$ 90 percent; in line items per policy.
S_LNITEM (6)	Total of items with availability $\geq$ 90 percent to $<$ 95 percent; in line items per policy.
S_LNITEM (7)	Total of items with availability $\geq$ 95 percent; in line items per policy.

IDENTITIES

The following identities are expressed in terms of a programming language assignment statement, where the identifier on the left at time t + 1 is replaced by the

expression on the right, evaluated at time t.

TRANS	=	DMD if total demand satisfied, else TRANS = ONH; in units of issue per line item.

#SOLD   = $\sum_{1}^{BM}$ TRANS; in units of issue per line item.

BNPRICE   = $\dfrac{ONH * PRICE + BQ * DUIN}{ONH + DUIN}$; in dollars per line item.

PRICE   =   BNPRICE; in dollars per line item.

ONH   =   ONH - TRANS + DUIN; in units of issue per line item.

DUIN   =   HQTY + (TIME/30) * PRD; in units of issue per line item.

PRD   =   PRD * (1 - BCONSTANT) + MDEM * BCONSTANT; in units of issue per line item.

HQTY   = $\sqrt{\dfrac{2 * HORDERCOST * AUF}{HHOLDCOST}}$ for EOQ; in units of issue per line item. (Other decision rules for HQTY are outlined in text.)

EXPEC   =   AND/(FREQ + NFREQ); in units of issue per line item.

STDV   =   EXPEC/2; in units of issue per line item.

NEX   =   AND/FREQ; in units of issue per line item.

MDEM   = $\sum_{BD = 1}^{30}$ DEMD; in units of issue per line item.

STDX   =   NEX/10; in units of issue per line item.

TRND   =   PRD - FCST1; in units of issue per line item.

TREND   =   (BCONSTANT * TRND) + (1 - BCONSTANT) * TREND; in units of issue per line item.

ERROR　　　　=　　　MDEM - EXPCDMD; in units of issue per
　　　　　　　　　　line item.

EXPCDMD　　=　　　PRD + TREND * (1 - BCONSTANT)/
　　　　　　　　　　BCONSTANT; in units of issue per line
　　　　　　　　　　item.

MAD　　　　=　　　ABS (BCONSTANT * ERROR) + (1 -
　　　　　　　　　　BCONSTANT) * MAD; in units of issue per
　　　　　　　　　　line item.

MRD　　　　=　　　((TIME/30) * EXPCDMD) + KFACT * MAD *
　　　　　　　　　　SQRT (TIME/30); in units of issue per
　　　　　　　　　　line item.

PARAMETERS

Identifier	Description
PRICE	Cost price of inventory item; in dollars per unit of issue.
TIME	Purchase lead time; in days per purchase order per line item.
BCONSTANT	Exponential smoothing constant; a decimal fraction.
BSAFE	Fraction of demand unsatisfied, for use in variable safety level computation; a decimal fraction.
BYRC	Number of years in total time period of simulation; in years per simulation cycle.
BD	Number of days per month; a numeric constant in the range one to thirty.
HORDERCOST	Order cost; in dollars per purchase action.
HHOLDCOST	Holding cost; in dollars per year.
HMAX	Maximum purchase quantity; in units of issue per transaction.
HMIN	Minimum purchase quantity; in units of issue per transaction.

HANNUAL$DMD   Annual dollar demand comparand
                                    for purchase quantity compu-
                                    tation; in dollars per year.

In order to provide for future demands against
inventory, it is usual to use past demand history as a
basis for forecasting this future demand. In this model,
exponential smoothing[2] was used to operate on past and
present demand to produce a forecast demand for use in
purchase quantity and safety level computation. Single
exponential smoothing is defined to be:

$$Y_t = \alpha X_t + (1-\alpha) Y_{t-1}$$

where Y_t is the average computed for the end of time
period t and X_t is the demand registered in time period t.
The smoothing process can be recursively applied,
yielding higher degrees of smoothing expressed by:

$$Y_t^k = \alpha Y_t^{k-1} + (1-\alpha) Y_{t-1}^k$$

where k is a superscript which defines the degree of
smoothing, and t indicates the time period in question.
Double smoothing, for example, requires the following
calculations:

$$Y_t^1 = \alpha X_t + (1-\alpha) Y_{t-1}^1$$

$$Y_t^2 = \alpha Y_t^1 + (1-\alpha) Y_{t-1}^2$$

While of interest for theoretical purposes, high
orders of smoothing in general provide little practical

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[2]Robert G. Brown, <u>Statistical Forecasting for
Inventory Control</u> (New York: McGraw-Hill Book Company,
1959), pp. 45-51.

benefit in terms of forecast accuracy, and obviously increase file storage space requirements and computation time. For these reasons, only single and double smoothing have been used in the model.

From the definition, however, it can be seen to be a trivial matter in PL/I to program a recursive function call for any desired degree, assuming the availability of k storage locations with each master file stock item for k^{th} degree exponential smoothing to hold the k values of y^k.

The specification of two alternative values for the α-constant in the forecasting routine is at the option of the user. For preliminary investigation, values of 0.2 and 0.4 are customary, but, of course, any values may be specified. The specification of the α-constants completes the first of the three sets of parameters needed to identify the twelve policies to be simulated.

The second set of parameters controls the purchase quantity computation. Here three choices are available for composing the twelve-policy set and the user may either use the three decision rules embedded in the program, specifying their parameters as desired, or entirely new rules may be specified in any combination with little additional effort.

When the stock on-hand gets to a certain level (CRIT) a computation is made to determine how much to purchase to replenish this stock. This aperiodic action

was taken in lieu of a periodic reorder cycle on the
assumption that we are dealing with high demand items
(as opposed to insurance items) and that if there is new
information, use should be made of it. This new infor-
mation is in the form of the variable safety level (CRIT)
and the total demand forecast. This philosophy could have
been carried one step further and a new exponentially
smoothed demand produced at this point, but with monthly
forecasting in use this was deemed unnecessary. The
purchase quantity computation methods were chosen in order
to provide three quite distinguishable computations so as
to give clear alternatives in the evaluation of the
results. The purchase quantity computation methods chosen
to model were:

1. Standard EOQ computation[3] with:

   HORDERCOST = Order cost = $70.

   HHOLDCOST = Holding cost = 15 percent of price.

   AUF = Annual demand from master file.

   HMAX = Maximum buy = twelve months of forecast
          demand.

   HMIN = Minimum buy = one month of forecast
          demand.

2. Modified EOQ computation with different para-
   meters in order to accentuate any distinction
   with the standard EOQ computation:

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[3]G. W. Plossl and O. W. Wight, Production and
Inventory Control (Englewood Cliffs, N. J.: Prentice-Hall,
Inc., 1967), pp. 388-390.

HORDERCOST = Order cost = $100.

HMAX = Maximum buy = twenty-four months forecast demand.

HHOLDCOST = Holding cost = 15 percent of price.

HMIN = Minimum buy = two months forecast demand.

The decision rule for the modified EOQ computation was to use the standard EOQ formula with the above parameters if the forecast annual demand in dollars was less than $1,000. If the annual demand forecast was equal to or greater than $1,000, but less than $10,000, the purchase was to be simply twelve months of predicted demand. Otherwise the standard EOQ formula was used with the above parameters except that HORDERCOST = $500.

    3.   Three way function of annual dollar demand forecast:

        1) If forecast dollar demand is less than $1,000, buy twenty-four months of forecast demand.

        2) If forecast dollar demand is equal to or greater than $10,000, buy two months of forecast demand.

        3) Otherwise buy six months of forecast demand.

These three methods represent enough of a variation so that the results show significant differences from which to choose. Of course any other set of purchase quantity computation methods could have been chosen. Since the number of simulation cycle runs is dependent on the

Cartesian product of the overall number of rules in each set under consideration, the addition of more rules must be considered with total run time in mind.

The third and last set of rules involves a choice of two performance levels or service levels.[4] The service level is in essence the _desired availability_ of stock in the system. For instance, a service level of 90 percent indicates that the system economics are expected to be able to satisfy 90 percent of the demand against system items. The parameter BSAFE may be set to reflect two different service levels which are to be investigated. If service level is defined as fraction of demand to be satisfied from stock, BSAFE will be defined as fraction of demand unsatisfied, or fraction of demand back ordered. If we are investigating the feasibility of system support for service levels of 95 percent and 98 percent, the values of the parameter BSAFE would be specified as 0.05 and 0.02. The principal use of this parameter is in the computation of the variable safety level,[5] CRIT. This safety level, or reorder point, varies with each item as the item's demand pattern changes. The variable safety level computation takes into account past forecast errors and produces a small safety level of stock for a well behaved demand pattern and a large safety level for a demand pattern

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[4]Brown, _Statistical Forecasting_, pp. 105-116.

[5]_Ibid._, pp. 136-159.

which produces large forecast errors. The variable safety
level computation is accomplished monthly, at forecast
time, for each stock item in the file.

For the purposes of this model, an inventory control
policy was defined to be one of the twelve possible com-
binations made by selecting one element from each of the
above three sets of parameters. For example, one policy
might be α = .15, standard EOQ with parameters as given in
the model, BSAFE = .02.

The user has the ability to specify initial stock
conditions and also the probability distributions for the
following variables:

1. Return of material to stock.

2. Frequency of demand.

3. Price change on receipt of material.

4. Quantity demanded against individual items.

In addition, the user may wish to simulate other types of
transactions than are provided for in the model. The
program modification in this case would be left to the
user. To allow flexibility in introducing new subroutines
to extend or change the model, the following pseudo-random
variate generators are available as simple PL/I function
calls:

1. Uniform.

2. Normal.

3. Poisson.

4. Geometric.

5. Gamma.

6. Binomial.

7. Hypergeometric.

8. Log-Normal.

9. Negative Binomial.

10. Exponential.

The index of the random variate generator in the above list corresponds to the value of the exogenous variable X (see page 9).

III. THE PRESENTATION TO THE DECISION MAKER

The simulation statistics that are available on a
monthly basis are shown in Figures 2, 3, and 4. Figure 1
is a three-dimensional representation of how data are
collapsed into the matrix in Figure 2. The matrix entries
correspond to the number of line items which fell into that
matrix element as of that point in time. The vertical
columns, or categories, are totaled to show the number of
line items in each price-demand category. The totals at
the bottom of the figure are sub-tabulated by the price-
demand categories. Only the total investment figure is
scaled. A scale of 100,000 was applied to this due to
restrictions on the allowable number of characters per line
on the display surface of the cathode ray tube. A total
investment of $423,251.81 would, therefore, be reflected
as $4.23.

Figure 3 is a tabular monthly recapitulation which
is ordered by several of the statistics of interest. This
is the counterpart of Figure 4 which shows one statistic
across all policies as a bar graph. The printed bar graphs
are produced monthly for lost sales, purchase order gener-
ation, total investment and stock availability.

Once the printer output was specified, it was
natural to attempt to reproduce this presentation on
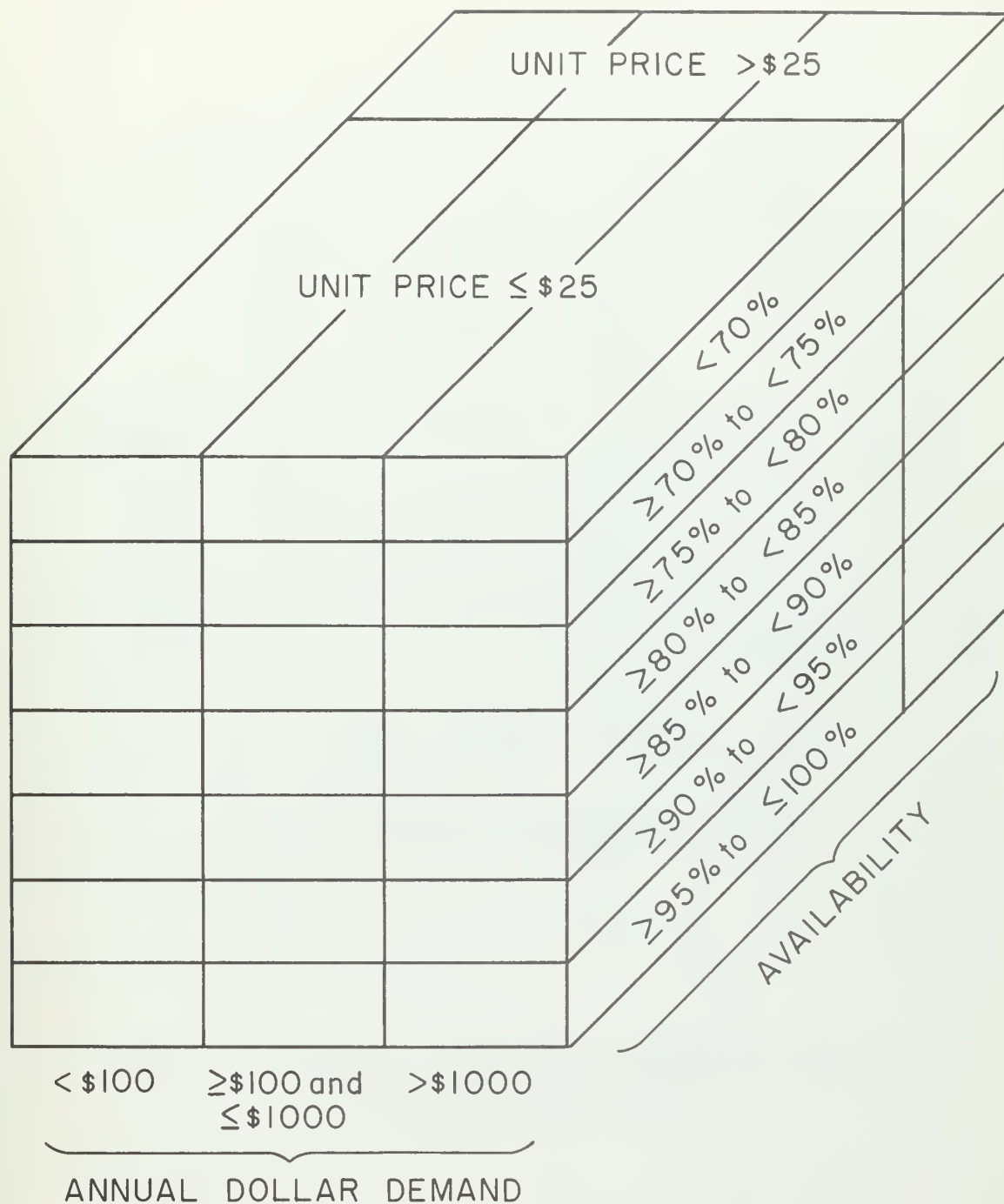
Fig. 1.--Three-dimensional representation of Figure 2

MONTH 16   POLICY   2   PROBLEM # 13

	UNIT PRICE < $25			UNIT PRICE > $25	
ANNUAL DOLLAR DEMAND AVAILABILITY	< $100	≥ $100 & ≤ $1,000	> $1,000		LINE TOTALS
< 70%	0	0	0	0	0
≥ 70% to < 75%	0	0	0	0	0
≥ 75% to < 80%	0	0	0	1	1
> 80% to < 85%	0	0	2	0	2
≥ 85% to < 90%	0	0	0	3	3
≥ 90% to < 95%	0	0	1	1	2
≥ 95% to ≤ 100%	5	4	13	7	29
CATEGORY TOTALS:	5	4	16	12	

TOTAL NUMBER OF ITEMS: 37

CATAGORY	LOST SALES	% AVAILABILITY	TOTAL INVESTMENT
1	$.00	99.99	$.01
2	$6.78	99.23	$.02
3	$16,583.44	93.97	$1.07
4	$125,480.56	89.69	$3.46
OVERALL:	$142,070.75	92.90	$4.57

CUMULATIVE NUMBER OF PURCHASE ACTIONS FOR THIS POLICY =   57
CUMULATIVE NUMBER OF TRANSACTIONS GENERATED UNDER THIS POLICY =   1931

Fig. 2.--Detailed listing of simulation results
by policy within month

MONTH   16   PROBLEM # 13

RESULTS OF SIMULATION BY : POLICY NUMBER

POLICY NUMBER	AVAILABILITY	TOTAL INVESTMENT	LOST SALES	PURCHASE ACTIONS	TRANSACTIONS
1	89.37	$3.40	$222,191.56	108	1937
2	92.90	$4.57	$142,070.81	57	1931
3	89.73	$2.73	$50,025.95	87	1984
4	89.32	$2.78	$153,479.62	73	1896
5	92.98	$4.79	$232,559.37	65	1956
6	91.01	$3.48	$224,220.50	89	1909
7	95.15	$2.77	$23,692.03	73	1933
8	96.31	$4.27	$42,522.65	56	1926
9	94.60	$4.16	$145,429.12	98	1881
10	86.68	$2.60	$144,235.37	71	1889
11	93.78	$5.37	$152,888.06	53	2018
12	93.46	$2.86	$85,199.18	61	1922

RESULTS OF SIMULATION BY : TOTAL INVESTMENT

POLICY NUMBER	AVAILABILITY	TOTAL INVESTMENT	LOST SALES	PURCHASE ACTIONS	TRANSACTIONS
10	86.68	$2.60	$144,235.37	71	1889
3	89.73	$2.73	$50,025.95	87	1984
7	95.15	$2.77	$23,692.03	73	1933
4	89.32	$2.78	$153,479.62	73	1896
12	93.46	$2.86	$85,199.18	61	1922
1	89.37	$3.40	$222,191.56	108	1937
6	91.01	$3.48	$224,220.50	89	1909
9	94.60	$4.16	$145,429.12	98	1881
8	96.31	$4.27	$42,522.65	56	1926
2	92.90	$4.57	$142,070.81	57	1931
5	92.98	$4.79	$232,559.37	65	1956
11	93.78	$5.37	$152,888.06	53	2018

RESULTS OF SIMULATION BY : AVAILABILITY

POLICY NUMBER	AVAILABILITY	TOTAL INVESTMENT	LOST SALES	PURCHASE ACTIONS	TRANSACTIONS
8	96.31	$4.27	$42,522.65	56	1926
7	95.15	$2.77	$23,692.03	73	1933
9	94.60	$4.16	$145,429.12	98	1881
11	93.78	$5.37	$152,888.06	53	2018
12	93.46	$2.86	$85,199.18	61	1922
5	92.98	$4.79	$232,559.37	65	1956
2	92.90	$4.57	$142,070.81	57	1931
6	91.01	$3.48	$224,220.50	89	1909
3	89.73	$2.73	$50,025.95	87	1984
1	89.37	$3.40	$222,191.56	108	1937
4	89.32	$2.78	$153,479.62	73	1896
10	86.68	$2.60	$144,235.37	71	1889

RESULTS OF SIMULATION BY : LOST SALES COSTS

POLICY NUMBER	AVAILABILITY	TOTAL INVESTMENT	LOST SALES	PURCHASE ACTIONS	TRANSACTIONS
7	95.15	$2.77	$23,692.03	73	1933
8	96.31	$4.27	$42,522.65	56	1926
3	89.73	$2.73	$50,025.95	87	1984
12	93.46	$2.86	$85,199.18	61	1922
2	92.90	$4.57	$142,070.81	57	1931
10	86.68	$2.60	$144,235.37	71	1889
9	94.60	$4.16	$145,429.12	98	1881
11	93.78	$5.37	$152,888.06	53	2018
4	89.32	$2.78	$153,479.62	73	1896
1	89.37	$3.40	$222,191.56	108	1937
6	91.01	$3.48	$224,220.50	89	1909
5	92.98	$4.79	$232,559.37	65	1956

Fig. 3.--Sorted listing of simulation results
by policies within month

Fig. 4.--Bar graph of simulation results
by month across all policies

another device for the experiment. The experimental

machine was chosen to be the IBM 2250 Model 1 cathode ray

tube display device.[6] See Figure 5. This particular

device is program controlled from the multiprogramming

environment of the IBM System 360 Model 40 computer at the

University of North Carolina Computation Center. A program

was written to take the data output of the simulation

program and mimic the printer output formats on the display

device. Some exploration of the power and utility of such

a display device was made within the confines of the

desirability of maintaining similar presentation format for

experimental design purposes. Figures 6 and 7 are the

display device representations of Figures 2 and 3 and show

some rearrangement of material due to display character and

line number limitations.[7] Figure 8 shows the first marked

departure from the printer output of Figure 4. The layout

is essentially the same, but the presentation is dynamic.

A programmed timer was specified in the display program to

advance all lines of the bar graph simultaneously at one

second intervals. If the user specifies a month at which

he wishes to examine the data, and then specifies the bar

---

[6]International Business Machines Corporation,
IBM System/360 Component Description, IBM 2250 Display
Unit Model 1, Form A27-2701-1 (January 27, 1967), pp. 5-37.

[7]International Business Machines Corporation,
IBM System/360 Operating System, Graphic Programming
Services for IBM 2250 Display Unit, Form C27-6909-4
(December 1967), p. 14.

Fig. 5.--IBM 2250 cathode ray tube display device

Fig. 6.--Display of Figure 2

MONTH 16
PROBLEM 13

POLICY	$ AVAILABLE	LOST SALES	TOT INVSTMNT	PURCHASES
1	89	$ 222,191	$ 3.40	108
2	92	$ 142,070	$ 4.57	57
3	89	$ 50,025	$ 2.73	87
4	89	$ 153,479	$ 2.78	73
5	92	$ 232,559	$ 4.79	65
6	91	$ 224,220	$ 3.48	89
7	95	$ 23,691	$ 2.77	73
8	96	$ 42,522	$ 4.27	56
9	94	$ 145,429	$ 4.16	98
10	86	$ 144,235	$ 2.60	71
11	93	$ 152,887	$ 5.37	53
12	93	$ 85,199	$ 2.86	61

------------------RESULTS SORTED BY MAJOR CATEGORY :------------------

POLICY	$AVAILABLE	POLICY	LOST SALES	POL. INVST.		POL. PURCH.	
8	96	7	23,691	10	$ 2.60	11	53
7	95	8	42,522	3	$ 2.73	8	56
9	94	3	50,025	7	$ 2.77	2	57
11	93	12	85,199	4	$ 2.78	12	61
12	93	2	142,070	12	$ 2.86	5	65
5	92	10	144,235	1	$ 3.40	10	71
2	92	9	145,429	6	$ 3.48	4	73
6	91	11	152,887	9	$ 4.16	7	73
3	89	4	153,479	8	$ 4.27	3	87
1	89	1	222,191	2	$ 4.57	6	89
4	89	6	224,220	5	$ 4.79	9	98
10	86	5	232,559	11	$ 5.37	1	108

Fig. 7.--Display of Figure 3

```
MONTH  16                          PROBLEM #  13

      LOST SALES IN INCREMENTS OF  4,000  DOL

   SCALE    04      40      80     120     160     200     240
            I       I       I       I       I       I       I
POLICY 1   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 2   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 3   >>>>>>>>>>>>>
POLICY 4   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 5   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 6   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 7   =====
POLICY 8   >>>>>>>>>>
POLICY 9   >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 10  >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 11  >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>
POLICY 12  >>>>>>>>>>>>>>>>>>>>>>
            I       I       I       I       I       I       I
   SCALE    04      40      80     120     160     200     240
```

Fig. 8.--Display of Figure 4

graph he wishes to see, the graph begins at month 1 and
then advances at one second intervals to the month
requested. The user may also specify half-second intervals
by a light pen detect. It is intended that this movement
of the bar graph give a feeling for the history and current
derivative of the statistic under scrutiny as well as the
static numeric results of the simulation. In addition to
the movement of the bar graph, the symbols $>$, $<$ and $=$
are used on the display unit to indicate whether the value
of a particular bar has increased, decreased or remained
equal in comparison with the previous month.

Figure 9 has no printed correspondent in this
experiment. While the data for cost of lost sales,
availability, total dollar investment and number of pur-
chase actions generated are available as individual bar
graphs as represented by Figure 8, all four of these are
available at the same time in the Quadrant Graph. All
move simultaneously under the same program timer control
as the individual graphs. Each graph is scaled uniquely
and, of course, represents the same data as are available
on the individual graphs, but with the obvious reduction
in resolution since each line of a graph has only approx-
imately half the width of the display device screen to
represent the data as does the individual graph.

Figure 10 depicts the Program Function Keyboard (PFK)
which is the means by which the user indicates to the
computer what he wishes to see on the display device.

Fig. 9.--Quadrant graph of simulation results
by month across all policies

Overlay Code

⓪ ① ② ③ ④ ⑤ ⑥ ⑦

INVENTORY
CONTROL PROGRAM

J. S. PROKOP

Instructions/ Termination 0	Month/ Policy 1	Month/ Policy 2	Month/ Policy 3
Month/ Policy 4	Month/ Policy 5	Month/ Policy 6	Month/ Policy 7	Month/ Policy 8	Month/ Policy 9
Month/ Policy 10	Month/ Policy 11	Month/ Policy 12	Month 13	Month 14	Month 15
Month 16	Month 17	Month 18	Month 19	Month 20	Month 21
Month 22	Month 23	Month 24	Sorted Listing 25	Availab. Graph 26	Lost Sales Graph 27
Purchase Graph 28	Investmt Graph 29	Advance 30	Quadrant Graph 31

Fig. 10.--Programmed function keyboard

Key 0 will always display the user instructions if the plastic overlay, with no sense switch cut-outs,[8] is in place. Otherwise, key 0 will return control to the graphics monitor.

There is a two-step procedure for obtaining a display:

1. Indicate which month is to be seen.

2. Indicate the display data desired.

In order to prevent inadvertent display of data beyond the month desired, month change was set up as a two-step action. First, key 30 must be depressed (at which time a tone signal is heard), then the key corresponding to the month is depressed. This key is lighted by program control as a reminder to the user of his simulated month of furthest advance. At this time, no change is noted on the display device screen. When a key corresponding to a display is depressed, the display then changes. Keys 1-12 will display Figure 6 for policies 1-12 for the month indicated. Keys 13-24 will be ignored by the program at this point. Note that keys 1-24 signify different events depending on whether they are immediately preceded by a key 30 depression or not. Key 25 will produce Figure 7, keys 26-29 will produce Figure 8 for Availability, Cost of Lost Sales, Purchase Actions Generated, and Total Dollar Investment respectively. Key 31 will produce Figure 9.

---

[8]IBM, Component Description, pp. 30-32.

The user is allowed to refer to any past month's data. He
may not, however, move ahead in simulated time by more than
one month at a time.

IV. THE SUBJECTS OF THE EXPERIMENT

The experiment was designed to examine the decision-making processes of experienced, practical and interested professional administrators of inventory control, to find out if graphical display devices do, in fact, assist the decision-making process. The subjects were solicited in such a way as to insure a professional audience. The short course was designed as a graduate-level course which would attract only those who were interested in the subject matter and who were prepared to understand the material. The simulation model was the experimental vehicle and was used in examples and problems which were integrated into the course. The participants came to the course in statistical inventory control for their own professional advancement, under the auspices of the firms for which they worked. The participants were not informed of the experiment which was being conducted, and they received the full measure of instruction for which they came. The control of the human factors in the experiment proceeded quite smoothly with nothing to indicate bias or data contaminated by the fact that an experiment was in progress.

The individuals who comprised the experimental group were solicited from nearby major manufacturing concerns specifically for the short course in statistical

inventory control. It was requested that candidates for the course have experience in inventory control and be in a decision-making position in the company. No more than two candidates were to be sponsored by any one company. The following firms sent people to the course:

> Burlington Hosiery, Burlington
>
> Burlington House Division, Burlington
>
> Cardinal Products, Durham
>
> Coca Cola, Durham
>
> Golden Belt Manufacturing Company, Durham
>
> International Business Machines, Raleigh
>
> Kayser-Roth Hosiery, Burlington
>
> Liggett and Meyers, Durham
>
> Sears Roebuck, Greensboro
>
> Sperry Rand, Durham
>
> Virginia Mills, Swepsonville
>
> Westinghouse Electric, Raleigh

The participants attended the course between the hours of 9:00 and 11:00 A.M. weekdays for a two-week period. The morning hours were chosen specifically to insure that the attendees would have the active concurrence and support of their sponsoring firms and would be scheduled for this absence from their regular duties.

After a random division into two groups of nine individuals each, the following statistics applied to the individuals:

Individual	Years Experience in Inventory Control	Automated Inventory Control Experience	Presently in Decision- Making Capacity
Group I			
A	20	No	Yes
B	15	No	Yes
C	20	No	Yes
D	12	Yes	Yes
E	1	No	No
F	5	Yes	Yes
G	10	Yes	Yes
H	1	Yes	Yes
I	2	No	Yes
Group II			
J	5	Yes	Yes
K	1	No	No
L	5	Yes	Yes
M	0	No	No
N	2	No	Yes
O	20	Yes	Yes
P	6	Yes	Yes
Q	2	No	Yes
R	2	No	Yes

After a substantial part of the course material had been given, the participants were given either a problem

book with twenty-four months of simulation output (Figures 2, 3, and 4) or assigned to work a problem on the display unit at individual laboratory sessions. The second problem was assigned later in a similar manner except the groups now used the presentation method that they had not used on the first problem. It was explained that congestion on the display unit precluded everyone working both problems in this way. There was no attempt made to identify individuals by group membership or emphasize this distinction.

The participants were not graded on these problems and were encouraged to work them as part of the education process of the course to investigate some of the fundamental properties of the inventory control policies. Although all of the inventory control policies simulated for the two problems were discussed in class, the participants were not given the correspondence to identify specific policies by number on the problem to avoid obvious bias. The participants, then, were asked to make their judgment based solely on the evidence without subjecting them to the prejudice of prejudgment. The two problems were of equivalent difficulty, the only distinction being the order in which they were presented.

An operational environment was explained for the problem. Higher level management had presented the participant with the output data for the set of twelve inventory control policies, and had requested a recommended ranking so that an implementation of policies could be decided

upon. The participant was encouraged by management to present his recommended ranking as soon as possible, but cautioned that implementation of the recommended policies could have serious repercussions in the firm, so his best professional judgment was required. Figure 11 was the work sheet to be used. Participants were told to ignore the first two items in the top line as they had no relevance in this problem (Group #, USING:). Participants were reminded to keep accurate figures on elapsed time spent studying each month's data, and were also reminded to mark the decision month at which they would have presented that ranking as a recommendation to higher level management, prior to completing the rest of the form.

In this experiment there were two possible approaches to the problem of evaluating the quality of the decisions made. The first and most commonly used approach is to establish and furnish the subjects with the criteria of excellence which is to be used in evaluating the decisions. For example, in many cases the subjects are first given instruction, then tested to ascertain how well they perform as measured against the pre-established criteria.

This method of measurement may be dependable when the material is objective and the criteria are easily established. In inventory control (and many other problems) the weightings to be used in reaching a decision are highly individual. For example, one firm may emphasize

GROUP # _____   USING: DISPLAY / PRINTOUT   PROBLEM # _____

DATE _____   START TIME _____   PRINT YOUR INITIALS : ___ ___ ___

```
              MONTH: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |10 |11 |12 |13 |14 |15 |16 |17 |18 |19 |20 |21 |22 |23 |24 |

UNDER EACH MONTH,  | BEST|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
RANK THE POLICIES  | 2ND|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
FROM BEST TO WORST.| 3RD|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
THEN ENTER THE TIME| 4TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
BEFORE GOING ON TO | 5TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
NEXT MONTH'S DATA. | 6TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
                   | 7TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
                   | 8TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
                   | 9TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
                   |10TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
                   |11TH|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
                   |WORST|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|

       CLOCK TIME|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
```

MARK "X" IN THIS ROW --->|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
UNDER THE MONTH IN WHICH
YOU HAVE MADE A FINAL
DECISION BEFORE GOING
THROUGH REST OF DATA TO
CHECK OUT YOUR DECISION.

Fig. 11.--Data collection format

high availability, whereas another may give heavy weight to low investment. When the experimental subjects are experienced in the field and have developed their own criteria for decisions, the method of measuring against instructor-set criteria is unsuitable. One cannot know the extent to which the subjects followed the instructor's criteria and the extent to which they followed their own.

A distinguishing feature of this experiment is that it took an alternative approach to the problem of evaluating the quality of decisions. The subjects were well acclimated to the decision process by experience, and were familiar with and interested in the substance of the course. Therefore, they were given no weightings, no criteria of excellence by the instructor. Instead they were explicitly told to apply their own several diverse sets of criteria. The quality of their decisions was then measured by the consistency of each subject's own ranking at the month of commitment with the later ranking when full information was available.

Although this second approach diminishes the meaningfulness of comparisons which show how well the subjects agree with each other, such measures were taken as a matter of interest. The use of self-consistency rather than artificial criteria does, however, improve the credibility of the other statistics. It also substantially improves the generalizability of the results, for it shows the effect on decision makers when deciding by their own

standards, rather than by those dictated by a simplified theoretical model. In substance, we have separated the decision process from the classroom environment and inserted it into an operational environment.

V. THE DESIGN OF THE EXPERIMENT

Two main analyses were performed on the data: an
analysis of variance of the Latin square design, and a
computation of rank order statistics. We will first turn
our attention to the Latin square design.

The concept of a generalized Latin square design is
traditionally introduced by explaining a checkerboard
pattern of equal-area plots of land used in agricultural
experiments. If we are investigating the effect of soil
treatment on the yield of a crop, the plots are chosen at
random in such a way that every row and every column is a
complete replication, which is to say that each treatment
will occur once and only once in each row and each column
on the checkerboard. In an experiment, this design tends
to avoid any systematic variations in effects, such as local
soil variations, which are not due to the treatment.

In the Latin square design of this experiment, it
should be noted that instead of experimenting on different
subjects in each cell of the square, the same experiment
group was involved in both cells of a row. In effect,
each group acted as its own control group. Experiments in
which the same subjects are used under all q treatments
require q observations on each subject, and are called
experiments with repeated measures. In this experiment

q = 2 since we are dealing with two treatments and each subject is observed twice. This variation on the standard Latin square is described in detail on the following pages.

The formal design proceeds from a specification of the model to an analysis of variance and hence of the significance of observed differences. In the analysis of variance, the sum of squares (SS) is computed for rows, columns and treatments. From this, a variance estimate, or mean square (MS), is calculated for rows, columns and treatments. This is accomplished by dividing each sum of squares by the degrees of freedom (df) corresponding to that sum of squares. From here an F test[9] is used to find the significance level of the variation under investigation. We will be most concerned with the significance of any variance due to treatment.

	Order 1	Order 2
Group I (9 Individuals)	Display	Printer
Group II (9 individuals)	Printer	Display

Fig. 12.--Latin square design

The 2 x 2 Latin square with repeated measures[10]

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[9]William L. Hays, Statistics for Psychologists (New York: Holt, Rinehart and Winston, 1963), pp. 368-369.

[10]B. J. Winer, Statistical Principles in Experimental Design (New York: McGraw-Hill Book Company, 1962), pp. 538-543.

of Figure 12 was used to analyze the data for:

1. Simulated calendar time to reach a decision (decision month),

2. Actual elapsed time to complete the rankings through the decision month,

3. Actual elapsed time to complete the problem after the decision month,

4. Correlation coefficients for the consistency of the committed decision with the final ranking,

in order to produce an analysis of variance of these statistics.

The particular design was chosen in part to isolate that variation due to natural differences between the experimental groups. As can be seen below, the separation of the source of variation due to group differences allows a better measure of that variation due to the form of data presentation, which is the statistic of real interest. An appropriate model for this 2 x 2 Latin square design is:[11]

$$E(X_{ijkm}) = \mu + \delta_k + \pi_{m(k)} + \alpha_i + \beta_j \qquad [1]$$

In [1], μ is the grand mean, δ_k represents the effects associated with groups, $\pi_{m(k)}$ the effects associated with subjects within groups, α_i the effects due to the order in which each subject did the two experiments and β_j the effects due to the form of data presentation. The analysis and expected values of the mean

[11]Ibid., p. 539.

squares are shown in Figure 13, for the 2 x 2 case of the
p x p Latin square with n observations in each cell. Here
A and B represent the factors associated with the α and β
effects.

Schematically the experiment may be represented by:

	a_1	a_2
c_1	b_1	b_2
c_2	b_2	b_1

Variation Source	df p=2, n=9	E (MS)
Between Subjects	np-1 = 17	
Groups	p-1 = 1	$\sigma_\varepsilon^2 + p\sigma_\pi^2 + np\,\sigma_\delta^2$
Subjects within Groups	p(n-1) = 16	$\sigma_\varepsilon^2 + p\,\sigma_\pi^2$
Within Subjects	np(p-1) = 18	
A (Order)	p-1 = 1	$\sigma_\varepsilon^2 + np\,\sigma_\alpha^2$
B (Treatment)	p-1 = 1	$\sigma_\varepsilon^2 + np\,\sigma_\beta^2$
Error (Within)	p(n-1)(p-1) = 16	σ_ε^2

Fig. 13.--Analysis of the 2 x 2 Latin square design

The computational procedure for the analysis of
variance involves a straightforward partition of the total
sum of squares.[12] For this particular Latin square design,
the computation is as follows:

Correction Factor	G^2/np^2	[2]
Total SS	$\sum X^2$	[3]

---

[12]Hays, Statistics for Psychologists, pp. 356-375.

Order $\qquad$ $\Sigma A^2/np$ $\qquad$ [4]

Treatment $\qquad$ $\Sigma B^2/np$ $\qquad$ [5]

Cell Total $\qquad$ $\Sigma (AB_{ij})^2/n$ $\qquad$ [6]

Paired Observations $\qquad$ $\Sigma P_{m(k)}^2/p$ $\qquad$ [7]

Row $\qquad$ $\Sigma C_k^2/np$ $\qquad$ [8]

$SS_a = [4] - [2]$ $\qquad$ [9]

$SS_b = [5] - [2]$ $\qquad$ [10]

$SS_{groups} = [8] - [2]$ $\qquad$ [11]

$SS_{subj.\ w.groups} = [7] - [8]$ $\qquad$ [12]

$SS_{error(within)} = [3] - [6]$ $\qquad$ [13]

The summations in all cases are over the whole experiment. $P_{m(k)}$ represents the sum of the q observations on person m in group k. G is the grand total; A, B, C, represent the sum of the np observations for their corresponding sources of variation.

The ratio for the F test is computed for each source of variation in the usual manner by taking the ratio of two mean square values of interest. F(u,v) will designate the F value where u is the number of degrees of freedom in the numerator of the ratio and v the number of degrees of freedom in the denominator. F(1,16) then for this experiment is:

$F(1,16) = MS_a/MS_{error(within)}$

$F(1,16) = MS_b/MS_{error(within)}$

$F(1,16) = MS_{groups}/MS_{subj\ w.groups}$

In order to test the error term for homogeneity of variance, [12] is also computed so as to provide the parts that may be checked by an F_{max} test.[13] This is accomplished by summing only over Group I and over Group II rather than over the whole experiment. In this way the two components so derived for [13] are tested at F(8,8) for an appropriate significance level. The magnitude of this F ratio indicates the extent to which the observed data conform to the model, and thus provides a partial check on the appropriateness of the model.

Since the values of the decision month are positive integers, a skewed distribution was suspected and found to be present. The nature of the decision is also such that higher variances would be expected to be associated with higher means. The values were, therefore, transformed following a standard procedure by taking the square root, to make the variances more homogeneous and at the same time to normalize the distribution.[14] It is this square root value which is used in the analysis of variance computations, and reported in the tables.

It is of interest to compare the rank order of the inventory control policies at the decision month and the rank order at the twenty-fourth month for each individual. This comparison gives a measure of each individual's

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[13]Winer, Statistical Principles, pp. 92-96, 542.

[14]Ibid., pp. 218-222.

consistency between the ranking decision made at the decision month and that ranking decision made when full information was available. These two rankings for each participant are compared by means of a Spearman rank correlation coefficient test.[15] The computational procedure is as follows:

$$r_s = 1 - \left(\frac{6 \sum D_i^2}{N(N^2-1)} \right) \qquad [14]$$

where D_i is the difference in ranking for the ith inventory control policy, and $N = 12$, the number of inventory control policies observed. Once computed, these values for r_s are treated as data for analysis in the Latin square design previously discussed.

Since the r_s values are known to have a skewed distribution, a transformation is made on each of the r_s values in order to place the data on symmetric scale, so as to normalize the distribution.[16] It is these transformed values for r_s which are used in the analysis of variance computations. The transformation is:

$$r_s \text{ transformed} = .5 \left(\ln \frac{1+r_s}{1-r_s} \right) \qquad [15]$$

This transformation is a routine procedure used on correlation coefficients and is justified and discussed in

[15]Hays, Statistics for Psychologists, pp. 643-646.

[16]R. G. D. Steel and J. H. Torrie, Principles and Procedures of Statistics (New York: McGraw-Hill Book Company, 1960), pp. 188-189.

detail in the reference.

In order to find the extent to which the members of each group ranked the policies the same way under the same conditions, Kendall's W coefficient of concordance[17] was computed for each cell of the Latin square. With this single statistic computed for each of the four cells, some comments can be made concerning the homogeneity of decisions under the conditions of each cell. The computation for Kendall's W statistic is as follows:

$$W = \left(\frac{12 \sum_j T_j^2}{m^2 N(N^2-1)} \right) - \frac{3(N+1)}{N-1} \qquad [16]$$

where for this experiment m = 9, the number of individuals doing the ranking; N = 12, the number of policies ranked; and T_j is the sum of the nine individual rankings given the jth policy (i.e., the sum of column j in Tables 9 through 16). The statistic W is based on the extent of variability among the respective sums of the ranks. The basic relationship is:

$$W = \frac{\text{variance of rank sums}}{\text{maximum possible variance of rank sums}}$$

which reduces to [16] . From this it can be seen that W indicates the degree of concordance, or how well the group members agreed among themselves as to the rankings.

Consider another statistic. For each of the

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[17]Hays, _Statistics for Psychologists_, pp. 656-658.

$\binom{9}{2} = 36$ pairs of subjects in a cell, calculate the
Spearman coefficient for their two policy rankings at the
decision month. The average of these coefficients is a
measure of the agreement among subjects. This average may
be computed directly from Kendall's W statistic by:

$$\text{average } r_s = \frac{mW-1}{m-1}$$

In the interpretation of the result of this computation it
should be noted that this experimental group was not
attempting to apply a common criterion of excellence in
making their decisions. Individual best judgment and
experience in the decision process guided the problem
solution. The course which the subjects attended neither
taught nor encouraged standards in decision making or in
performance goals.

The difference between the two values of r_s just
discussed is that the single value of average r_s derived
by way of Kendall's W statistic is a measure of concordance
among all nine participants within a cell, whereas the
individual values of r_s derived from Spearman's test are a
measure of each person's consistency.

VI. RESULTS

The data analyzed and the results of the analysis
appear in the following tables. The results were computed
by PL/I routines. using single precision floating point
arithmetic. Where the tables appear in the form of the
Latin square, each cell is represented as in Figure 12.
The order of the participants in the listings is constant
over the tables presented; that is, the ith data element
always refers to the ith individual regardless of which
table is referenced. The within-cell mean and standard
deviation, corrected for sample size, are included in the
data lists.

In the analysis of variance we are examining the
two treatment hypotheses:

$$H_0 : \mu_P = \mu_D$$

$$H_1 : \mu_P > \mu_D$$

That is, the null hypothesis is that the mean associated
with the display unit is equal to the mean associated with
the printer output. Since we believe that the display
unit is, in fact, the better decision-making tool of the
two, the alternative hypothesis is that the mean associated
with the printer output is strictly greater than the mean
associated with the display unit. We are also comment-

ing on the two order hypotheses:

$$H_0 : \mu_{01} = \mu_{02}$$

$$H_1 : \mu_{01} > \mu_{02}$$

involving the means associated with Order 1 and Order 2.
The usual method in statistical hypotheses testing involves
setting the significance level of the test in advance of
obtaining the data. The convention used in the analysis of
variance deviates somewhat from this formality. The value
of F is reported to exceed a specified percentile by a
comparison with tables of critical values. The choice of
the significance level is in this way determined partly by
the data itself.[18] This allows each reader to establish
his own significance level and to judge the results there-
by. We will consider a conclusion to be more surely
established if the probability of its truth is higher.
This methodology does not allow a measure of the power of
the test; however, the procedure is valid for estimating
the probabilities of the observation in relationship to the
assumed sampling distribution. In this preliminary inves-
tigation we would be encouraged to find significance at
the .05 level, and the significance levels actually
attained are noted in the tables.

In this analysis of variance, we are principally
interested in investigating the effect of the treatment on
the subjects. We will also be interested in commenting on

_____

[18]Winer, Statistical Principles, p. 55.

the effect of <u>order</u> on the subjects. The results which
correspond to these effects will be referred to as the
<u>within-subject</u> sources of variation. We have also reported
the effect which corresponds to differences between Group I
and Group II as the <u>between-subject</u> source of variation.
The results of the various analysis of variance computations
are shown in Tables 2, 4, 6, and 8.

In the analysis of variance for the ordinal value of
the decision month, we were compelled to use a trans-
formation to produce a more symmetric distribution of
values, as noted in Chapter V. Both the original values
for this month and the transformed values are presented
in Tables 1a and 1b, respectively. These values represent
how many months of data the participants needed prior to
committing themselves to a decision on the rank ordering
that they would recommend. The question is: How early in
simulated time can a decision be made?

The null hypothesis that the variance is equal over
the groups cannot be rejected, as the F_{max} test indicates
(Table 2). The significance level of .10 appears to be
marginal, and we cannot really say that we accept the null
hypothesis either. However, we are sufficiently satisfied
with this result to have confidence in the validity of the
analysis of variance for the treatment factor. For the
<u>treatment</u> factor, H_0 is not supported at the .01 level.
We can say with a high degree of assurance that the mean
decision month arrived at by using the display unit was

TABLE 1a

ORDINAL VALUE OF DECISION MONTH

	Order 1		Order 2	
Group I	13 6 8 10 12 10 19 8 6	Display mean=10.222 σ = 4.086	14 14 13 11 17 14 14 12 10	Printer mean=13.222 σ = 2.048
Group II	9 9 10 8 13 8 6 12 9	Printer mean= 9.333 σ = 2.121	8 7 9 8 10 7 7 7 10	Display mean= 8.111 σ = 1.269

indeed less than that using the printer output. From another viewpoint, the participants on the average needed to look at less data volume with the display unit to make a committing decision than they did with the printer output. There is only a 1 percent probability that these observed differences are due to chance effects. No effect can be attributed to <u>order</u>, as indicated by the significance level of .25 for order.

Reference to Table 1a gives some additional information on the characteristics of the data within each cell. Within each group, the mean decision month is lower for the presentation on the display unit. The standard deviation

TABLE 1b

TRANSFORMED ORDINAL VALUE OF DECISION MONTH

	Order 1		Order 2	
Group I	3.605 2.449 2.828 3.162 3.464 3.162 4.358 2.828 2.449	Display mean=3.145 σ = .607	3.741 3.741 3.605 3.316 4.123 3.741 3.741 3.464 3.162	Printer mean=3.626 σ = .282
Group II	3.000 3.000 3.162 2.828 3.605 2.828 2.449 3.464 3.000	Printer mean=3.037 σ = .346	2.828 2.645 3.000 2.828 3.162 2.645 2.645 2.645 3.162	Display mean=2.840 σ = .219

does not follow this pattern however. For Group I, the
standard deviation, σ, of values for the display unit
presentation, 4.086, is considerably higher than for the
printer output, 2.048, while just the opposite is true for
Group II (1.269 vs. 2.121). In other words, both groups
had a higher σ for Order 1 than they had for Order 2.
Apparently there was some maturation between Order 1 and
Order 2 which was reflected in σ, but not in the mean in
both groups. The participants who were presented with
Order 1 on the display unit were encountering both a unique
problem and a unique way of analyzing the data, whereas
Group II presented with Order 1 used a familiar data

TABLE 2

ANALYSIS OF TRANSFORMED DECISION MONTH

Variation Source	SS	df	MS	F(1,16)	Significant at
Between Subjects					
Groups	1.797	1	1.797	8.485	.05
Subjects w/in Groups	3.390	16	0.211		
Within Subjects					
Order	0.181	1	0.181	1.877	.25
Treatment	1.034	1	1.034	10.709	.01
Error (Within)	1.546	16	0.096		

Homogeneity of Variance, F_{max} Test:

Variation Source	SS	df	F(8,8)	Significant at
Within Subjects				
Error (Within) Group I	1.148	8		
Error (Within) Group II	.398	8	2.884	.10
	1.546	16		

presentation for data analysis. Note that one very cautious participant, who waited until the nineteenth month to commit himself to a ranking, did quite a bit of damage to the standard deviation for the Group I, Order 1 cell.

The elapsed clock time which was required for a participant to commit himself to a ranking is given in Table 3, and its analysis of variance in Table 4. The null hypothesis of homogeneity of variance cannot be rejected by the F_{max} test, allowing us to accept the results of the analysis of variance.

The treatment factor is shown to be significant at much beyond the .001 level. The mean time to decision using the display unit is with great certainty less than that using the printer output. This indicates that the amount of time spent in making a decision was significantly reduced in this experiment by using the display device, which may point to an ability to assimilate a large quantity of data and to correlate these data by using display techniques, as opposed to printer output. The convenience of having virtually instantaneous recall of data displays by using the Programmed Function Keyboard is certainly a consideration in the interpretation of the results. Pushing buttons is just inherently faster than paging through a book of data, however well arranged and indexed the book may be. However much or little this consideration entered into the results, we still can give credence to the

TABLE 3

ELAPSED TIME IN MINUTES TO DECISION MONTH

	Order 1		Order 2	
	63		67	
	35		85	
	75		127	
	68	Display	72	Printer
Group I	88	mean=64.666	115	mean=89.777
	79	$\sigma=18.500$	70	$\sigma=23.156$
	81		114	
	52		89	
	41		69	
	52		41	
	69		29	
	60		47	
	66	Printer	31	Display
Group II	109	mean=73.444	43	mean=39.222
	61	$\sigma=19.255$	48	$\sigma=6.457$
	95		38	
	61		37	
	88		39	

proposition that data can be correlated faster and retained
better from a properly programmed display unit.

Unsolicited comment from individual participants
supported this conjecture without exception. The obser-
vation of the author is that the dynamic graphs gave the
participant a much better intuitive feel for the situation,
and that he was more likely to retain this impression and
not have to refer to past data repeatedly. One consider-
ation in this observation was the program control which
always started the dynamic graphs at month 1 and brought
them up to the current month in increments of one second.
This forced a continual review of the history and

TABLE 4

ANALYSIS OF DECISION TIME

Variation Source	SS	df	MS	F(1,16)	Significant at
Between Subjects					
Groups	3927.125	1	3927.125	9.161	.01
Subjects w/in Groups	6858.125	16	428.632		
Within Subjects					
Order	186.750	1	186.750	0.861	not
Treatment	7921.000	1	7921.000	36.531	$\ll$.001
Error (Within)	3469.250	16	216.828		

Homogeneity of Variance, F_{max} Test:

Variation Source	SS	df	F(8,8)	Significant at
Within Subjects				
Error (Within) Group I	1806.43	8		
Error (Within) Group II	1662.78	8	1.086	not
	3469.21	16		

derivative of the measure under consideration and undoubtedly reinforced past impressions. It was seldom that a participant asked that the graph be stopped at a month prior to his current month so that he could review the static situation as of that past instant. As a matter of interest, it was noted when the experiment was well under way that the more experienced participants used the dynamic graphs extensively, where the less experienced participants relied on the tabular listings presented on the display unit.

Referring to Table 3, we note that both the mean time to make this decision and the standard deviation within the cell are considerably reduced in favor of the display unit over the printer output. Group I, in going from display unit presentation to printer output presentation, showed a mean increase of about twenty-five minutes to make a decision, and an increase in σ. Group II, in going from printer output to display unit presentation, showed a mean decrease of about thirty-four minutes and a very sharp drop in σ. It might be argued that in spite of the maturation between Order 1 and Order 2, Group I did better on the display unit, and that the very noticeable difference between Order 1 and Order 2 statistics for Group II is due only in part to this maturation. It is interesting to note that only one participant (Participant F) made a faster decision using the printer output than using the display unit. If we examine the data in terms

of order, it can be seen that within each order the display
device gave more favorable results in terms of mean and
standard deviation than did the printer output.

The statistics of Tables 5 and 6 for the total
elapsed time to complete the problem after the decision
month, and its analysis of variance, are included for
interest. It can reasonably be assumed that there was some
speed-up by participants after they had made their decision
to commit, simply to get to the end to see how well they
did. There is some evidence of this speed-up in the time
data. How much of this is due to increased familiarity with
the problem at hand and how much is due to impatience to get
to the final result is difficult to say. The elapsed time
after the decision month was tempered by the requirement
that the data be ranked at each month. From personal
observation, the participants appeared to be conscientious
about following the spirit and the letter of the instruc-
tions, but relieved that the big decision had been reached,
and were in a hurry to finish the twenty-four months to
check their final ranking against their decision month
ranking.

Table 6 shows that the hypothesis of homogeneous
variance cannot be rejected, and we can go directly to
comment on the within-subject sources of variation. Here
the order statistics show that H_0 cannot be supported at
the .01 level, which is sufficient to support a statement
that we accept H_1. The order factor is thus seen to show

65

TABLE 5

TIME IN MINUTES TO COMPLETE THE PROBLEM
AFTER THE DECISION MONTH

	Order 1		Order 2	
Group I	62 71 87 64 50 64 21 56 63	Display mean=59.777 σ=17.788	41 47 54 55 28 32 70 35 39	Printer mean=44.555 σ=13.314
Group II	58 36 83 65 68 106 93 54 91	Printer mean=72.666 σ=22.237	57 51 55 52 54 46 66 53 25	Display mean=51.000 σ=11.135

significance here, wnich is reasonable and consistent with our previous comments on the effects of order. In this test the treatment factor was completely without significance which is also a reasonable result in view of the observation concerning the impatience to finish the problem. Reference to Table 5 shows a completely order-dependent data structure.

In Table 8, the analysis of variance statistics for the transformed Spearman rank correlation coefficient, r_s, are presented. The F_{max} test is satisfactory in our investigation of equal variances, so we turn our attention

TABLE 6

ANALYSIS OF TIME TO COMPLETE PROBLEM
AFTER DECISION MONTH

Variation Source	SS	df	MS	F(1,16)	Significant at
Between Subjects Groups	841.000	1	841.000	3.882	.10
Subjects w/in Groups	3466.000	16	216.625		
Within Subjects Order	3061.750	1	3061.750	9.018	.01
Treatment	93.437	1	93.437	0.275	not
Error (Within)	5431.812	16	339.488		

Homogeneity of Variance, F_{max} Test:

Variation Source	SS	df	F(8,8)	Significant at
Within Subjects Error (Within) Group I	2513.78	8		
Error (Within) Group II	2918.00	8	1.160	not
	5431.78	16		

to the within-subject sources of variation. Here our
hypotheses must be modified to read:

Treatment Factor   Order Factor

$H_0: \mathcal{M}_D = \mathcal{M}_P$ $H_0: \mathcal{M}_{O1} = \mathcal{M}_{O2}$

$H_1: \mathcal{M}_D > \mathcal{M}_P$ $H_1: \mathcal{M}_{O2} > \mathcal{M}_{O1}$

The hypothesis of equal means for the treatment factor, H_0,
cannot be supported at the .05 level. With a significance
level of .05, we obviously do not have the clear mandate
that our other treatment factor statistics have given, but
we are willing to claim that the evidence points towards
rejection of H_0 and acceptance of H_1; that is the mean
correlation coefficient is higher using the display unit
than using the printer output. The values of r_s give a
correspondence between the participant's ranking of the
policies at the decision month and his ranking at the last
month of the simulation data, month 24. This, then, is a
measure of the consistency between these two rankings. It
is also a measure of the participants discrimination abil-
ity - that is his ability to decide whether he has enough
information to commit himself to a ranking or not. A
decision to commit too soon in relation to each individual's
ability and ranking criteria would, in most cases, result
in a poor correlation coefficient, whereas being overly
cautious and waiting beyond the point where he had suffi-
cient information could not be expected to materially
improve the correlation coefficient. Thus, we might say
that one interpretation of a low r_s would be that the

participant committed himself too early. Other interpre-
tations are, of course, that he simply used poor judgment
in his ranking, or that he materially changed his ranking
criteria after the decision month. Participants were
cautioned to use a consistent ranking schema throughout.
As an extreme example, it was pointed out to the class that
to rank the policies based only on lost sales data through
the decision month, then to abandon that schema and to rank
the policies only on number of purchase orders generated
would not be showing responsible judgment. On the basis of
these comments, we should be able to narrow our consider-
ation of a principal cause of low r_s to either too early
commitment or poor ranking judgment at some point. Both
of these essentially are measures of decision-making
ability and we can accept either one or both as reasonable
interpretations of a low correlation coefficient.

From Table 8, we can see that the <u>order</u> factor is
highly significant; the probability that the mean of
Order 1 is equal to the mean of Order 2 is something less
than 0.1 percent. Thus we accept the alternative
hypothesis, H_1, that the mean of Order 2 is greater than
the mean of Order 1. The maturation between Order 1 and
Order 2 would appear to play a large role in the decision
making consistency that is being measured. That is, the
ability to meaningfully rank a set of policies grows with
practice, and moreover, improves more than the actual time
and simulation decision month considerations previously

TABLE 7a

SPEARMAN RANK CORRELATION COEFFICIENT r_S

	Order 1		Order 2	
	.615		.755	
	.405		.832	
	.118		.685	
	.412	Display	.559	Printer
Group I	.447	mean=.501	.965	mean=.647
	.671	σ=.195	.706	σ=.255
	.713		.552	
	.734		.055	
	.475		.713	
	-.062		.678	
	.398		.741	
	-.580		.811	
	.279	Printer	.720	Display
Group II	.209	mean=.126	.720	mean=.760
	.188	σ=.302	.923	σ=.073
	.405		.762	
	.209		.783	
	.090		.706	

measured. Reference to Table 7a shows that the mean for
both groups increased from Order 1 to Order 2, but that the
standard deviation for both groups under the display unit
treatment was less than the standard deviation for both
groups under the printer output presentation. The data for
the standard deviation in this table are of the same
general pattern as the data for the standard deviation in
Table 3, but Table 7a is the only table examined so far in
which the means within both groups increased with order.
One prominent difference in this comparison is that
Group II performed very poorly under the printer output
for Order 1 and quite well under the display output for

TABLE 7b

TRANSFORMED SPEARMAN RANK CORRELATION COEFFICIENT r_S

	Order 1		Order 2	
Group I	0.717 0.430 0.119 0.438 0.481 0.813 0.893 0.937 0.517	Display mean=.594 σ=.266	0.985 1.195 0.839 0.632 2.014 0.879 0.621 0.056 0.893	Printer mean=.901 σ=.524
Group II	-0.063 0.421 -0.663 0.287 0.212 0.191 0.430 0.212 0.091	Printer mean=.124 σ=.332	0.825 0.953 1.130 0.908 0.908 1.609 1.001 1.053 0.879	Display mean=1.030 σ= .236

Order 2. The lowest and highest means and standard deviations for all four cells are found in the Group II data. The use of printer output for Group II had the highest standard deviation, and the lowest mean, while the use of the display device for this group had the highest mean and the lowest standard deviation. Interpretation of the data from Table 7a in conjunction with the treatment factor data from Table 8 gives more credibility to the acceptance of H_1 for the treatment factor.

Tables 9 through 12 show the rankings of each policy by the participants at the decision month. Each of the tables represents one cell of the Latin square. For

TABLE 8

ANALYSIS OF TRANSFORMED SPEARMAN RANK
CORRELATION COEFFICIENT, r_s

Variation Source	SS	df	MS	F(1,16)	Significant at
Between Subjects Groups	0.262	1	0.262	2.759	.25
Subjects w/in Groups	1.522	16	0.095		
Within Subjects Order	3.310	1	3.310	20.546	<.001
Treatment	0.804	1	0.804	4.993	.05
Error (Within)	2.577	16	0.161		

Homogeneity of Variance, F_{max} Test:

Variation Source	SS	df	F(8,8)	Significant at
Within Subjects Error (Within) Group I	1.854	8		
Error (Within) Group II	.723	8	2.563	.25
	2.577	16		

example, in Table 9, Participant A ranked policy 1 as
eleventh and policy 2 as seventh at the decision month. To
demonstrate the correspondence among the tables, reference
to Table 1a and Table 3 shows that Participant A reached
this ranking at month 13 after an elapsed time of sixty-
three minutes. For Tables 9 through 12, Kendall's W
statistic and more importantly, the derived value of
average r_S is indicated. The values of average r_S from
these tables are summarized as follows in our usual format:

	Order 1	Order 2
Group I	Display $r_S=.574$	Printer $r_S=.664$
Group II	Printer $r_S=.543$	Display $r_S=.829$

As was the case in Table 7a, the effect of order is evident
here from the increase in average r_S from Order 1 to
Order 2 in both groups, and the most prominent increase is
in the movement from printer to display unit output in
Group II. Within the consideration of order, the cell
which represents the display unit data had the higher
value of r_S for both Order 1 and Order 2. This would tend
to indicate for this experiment that whatever the order,
a more homogeneous ranking was made by the participants
under display unit presentation than under printer output
presentation.

TABLE 9

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR UPPER LEFT QUADRANT
OF LATIN SQUARE; GROUP I,
ORDER 1, DISPLAY UNIT

Partici-pant	Policy Number											
	1	2	3	4	5	6	7	8	9	10	11	12
A	11	7	6	2	10	4	9	12	1	8	5	3
B	6	2	7	4	10	5	12	8	9	11	1	3
C	7	3	8	1	9	6	12	11	2	10	4	5
D	8	4	9	1	10	5	11	12	3	7	6	2
E	12	10	2	3	6	7	5	11	4	8	9	1
F	3	1	8	5	9	6	12	11	7	10	2	4
G	7	5	8	11	6	1	12	9	3	10	2	4
H	9	2	8	1	7	6	12	11	3	10	5	4
I	9	2	6	4	10	7	12	11	5	8	1	3

Summary of ranking by participants at decision month;

$$W = .621$$

$$\text{average } r_s = .574$$

TABLE 10

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR UPPER RIGHT QUADRANT
OF LATIN SQUARE; GROUP I, ORDER 2,
PRINTER OUTPUT

| Partici- | Policy Number | | | | | | | | | | | |
pant	1	2	3	4	5	6	7	8	9	10	11	12
A	9	5	12	7	11	10	1	3	4	8	6	2
B	6	2	12	8	9	7	1	3	5	10	11	4
C	7	4	11	8	10	9	1	3	5	6	12	2
D	6	7	5	8	11	10	2	3	4	9	12	1
E	6	1	12	9	7	10	3	2	5	11	8	4
F	3	2	12	9	8	5	4	1	7	10	11	6
G	6	3	12	5	8	10	2	1	7	11	9	4
H	10	9	6	11	8	3	2	1	7	5	12	4
I	7	3	6	8	11	10	1	4	5	9	12	2

Summary of ranking by participants at decision month;

$$W = .701$$

average $r_s = .664$

TABLE 11

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR LOWER LEFT QUADRANT
OF LATIN SQUARE; GROUP II, ORDER 1,
PRINTER OUTPUT

| Partici- | Policy Number | | | | | | | | | | | |
pant	1	2	3	4	5	6	7	8	9	10	11	12
J	9	5	6	1	7	3	11	12	4	10	8	2
K	6	1	9	2	10	3	11	12	5	8	4	7
L	7	3	2	12	1	4	6	10	8	5	9	11
M	4	1	6	5	7	8	12	10	9	11	3	2
N	6	1	7	3	10	4	11	12	5	8	9	2
O	4	1	6	3	9	7	12	10	8	11	2	5
P	7	4	9	3	10	6	12	11	5	8	1	2
Q	4	1	7	2	8	5	11	12	9	10	6	3
R	7	2	9	1	10	6	11	12	3	8	4	5

Summary of ranking by participants at decision month;

$$W = .593$$

$$\text{average } r_s = .543$$

TABLE 12

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR LOWER RIGHT QUADRANT
OF LATIN SQUARE; GROUP II,
ORDER 2, DISPLAY UNIT

Partici-pant	Policy Number											
	1	2	3	4	5	6	7	8	9	10	11	12
J	9	3	6	8	10	11	2	4	5	7	12	1
K	7	3	6	9	11	12	2	4	5	8	10	1
L	6	2	7	8	11	10	4	1	5	9	12	3
M	6	1	3	9	11	10	4	2	5	8	12	7
N	6	4	7	8	11	9	1	3	5	10	12	2
O	3	2	6	7	9	11	5	1	4	12	10	8
P	6	1	8	9	12	11	2	4	5	7	10	3
Q	5	2	6	8	9	11	7	1	3	10	12	4
R	6	3	7	9	11	10	2	4	5	8	12	1

Summary of ranking by participants at decision month;

$$W = .848$$

average r_s = .829

It should be emphasized that the value of average r_S derived by way of Kendall's W statistic (Tables 9 through 12) is a measure of concordance among all nine participants within a cell, whereas the values of r_S derived from Spearman's test (Table 7a) are a measure of each person's consistency. It is also worthwhile commenting again that the concordance was not measured against predetermined criteria, but rather reflects the degree to which experienced decision makers tended to agree under different treatments but using their own best judgment.

Tables 13 through 16 give the results of the decision process at the end of the twenty-fourth month when the decider had full information available to him. These tables represent the data in the same manner as did Tables 9 through 12. That is, in Table 13, Participant E ranked policy 1 as last, policy 2 as tenth and policy 3 as ninth. The resulting average r_S is represented in our usual Latin square format as:

	Order 1	Order 2
Group I	Display .639	Printer .856
Group II	Printer .485	Display .947

Here the pattern is much the same as it was for the decision month average r_S (see page 72), except that the

TABLE 13

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR UPPER LEFT QUADRANT
OF LATIN SQUARE AT TWENTY-FOURTH
MONTH; GROUP I, ORDER 1
DISPLAY UNIT

Partici-pant	Policy Number											
	1	2	3	4	5	6	7	8	9	10	11	12
A	12	6	7	9	10	8	5	11	1	4	2	3
B	8	1	11	12	7	5	9	10	3	6	2	4
C	11	5	10	12	6	9	7	8	1	3	2	4
D	12	5	9	11	7	4	8	10	2	6	1	3
E	12	10	9	4	7	11	5	6	3	8	1	2
F	6	1	8	12	10	4	11	9	3	7	2	5
G	7	4	12	10	5	8	11	6	2	9	1	3
H	12	5	11	4	6	8	10	9	2	7	1	3
I	9	1	11	12	7	6	8	10	2	4	3	5

Summary of ranking by participants at twenty-fourth
month:

$$W = .679$$

$$\text{average } r_s = .639$$

TABLE 14

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR UPPER RIGHT QUADRANT
OF LATIN SQUARE AT TWENTY-FOURTH
MONTH; GROUP I, ORDER 2
PRINTER OUTPUT

| Partici- | Policy Number | | | | | | | | | | | |
pant	1	2	3	4	5	6	7	8	9	10	11	12
A	7	2	11	8	6	12	3	1	5	10	9	4
B	6	2	10	9	7	11	3	1	4	12	8	5
C	7	2	10	9	6	11	3	1	5	12	8	4
D	7	1	10	9	6	11	3	2	5	12	8	4
E	6	2	10	9	7	11	3	1	4	12	8	5
F	4	2	8	10	6	11	5	1	3	12	9	7
G	7	2	6	10	12	9	3	5	4	8	11	1
H	7	2	9	6	4	12	5	1	3	11	10	8
I	6	1	10	9	7	11	3	2	4	12	8	5

Summary of ranking by participants at twenty-fourth
month:

$$W = .872$$

$$\text{average } r_s = .856$$

TABLE 15

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR LOWER LEFT QUADRANT
OF LATIN SQUARE AT TWENTY-FOURTH
MONTH; GROUP II, ORDER 1
PRINTER OUTPUT

Partici-	Policy Number											
pant	1	2	3	4	5	6	7	8	9	10	11	12
J	12	8	11	5	9	10	4	3	6	7	1	2
K	10	1	12	11	7	6	8	9	2	4	3	5
L	12	11	9	5	8	10	1	4	3	7	6	2
M	6	5	3	12	11	10	9	1	7	8	2	4
N	12	2	11	10	6	7	8	9	3	5	1	4
O	8	2	9	12	11	10	7	4	3	6	1	5
P	9	1	11	12	7	5	8	10	2	4	3	6
Q	8	1	11	12	7	5	9	6	3	10	2	4
R	12	8	11	10	5	9	6	7	2	4	1	3

Summary of ranking by participants at twenty-fourth
month:

$$W = .542$$

$$\text{average } r_s = .485$$

TABLE 16

DATA AND RESULTS FROM KENDALL'S W STATISTIC
COMPUTATIONS FOR LOWER RIGHT QUADRANT
OF LATIN SQUARE AT TWENTY-FOURTH
MONTH; GROUP II, ORDER 2
DISPLAY UNIT

Partici- pant	Policy Number											
	1	2	3	4	5	6	7	8	9	10	11	12
J	7	4	10	9	6	11	2	1	5	12	8	3
K	6	2	10	9	7	11	3	1	5	12	8	4
L	6	2	10	9	7	11	3	1	5	12	8	4
M	5	1	9	8	7	11	4	2	3	12	10	6
N	7	2	11	9	6	10	3	1	5	12	8	4
O	4	2	9	8	6	11	5	1	3	12	10	7
P	6	1	10	9	7	11	3	2	4	12	8	5
Q	5	2	11	8	7	9	3	1	4	12	10	6
R	6	1	10	9	7	11	3	2	4	12	8	5

Summary of ranking by participants at twenty-fourth
month:

$$W = .953$$

$$\text{average } r_s = .947$$

effect of Group II going from printer output at Order 1

to display unit output at Order 2 is much more pronounced.

There was a moderate increase in the average r_s for Group I

going from display to printer output, which may be ascribed

in part to maturation. However, the average r_s almost

doubling in Group II when going from printer output to

display output may be more than can plausibly be ascribed

to maturation alone. In comparing these results with the

average r_s results from Tables 9 through 12, it would be

well to remember that the rankings from those tables did

not represent the rankings made all at the same month. In

the case of the rankings at the twenty-fourth month, the

values of average r_s may be a more valid measure of con-

cordance since the decision relating to the ranking is not

confused with the additional decision of when to indicate

a decision month. In the rankings at the twenty-fourth

month, the deciders all had the same amount of information

available to them, which was not the case for the decision

month rankings.

point to the use of a display presentation when economy of time or simply volume of printed output is a serious constraint on the system or the decision maker.

While the two results reported above have the rigorous respectability of high statistical significance, the next results to be discussed are at least as important in the evaluation of the experiment. These are the results which answer the question of whether a better decision can be made with a display device. Because of the criteria used, we will claim that a decision at the month of commitment that is more consistent with the final decision is a better decision, and also that a decision which exhibits evidence of higher concordance among group members is a better decision. However, the two major results listed above would be convincing in their own right even if the decisions turned out to be no worse using a display device.

The results from Kendall's W statistic and from Spearman's rank correlation statistic show that individuals tended to make more consistent decisions with themselves and with their group using display device presentation techniques. Casual inspection indicates the conclusions established by the statistical analysis; within order, individuals made more consistent decisions using the display. It is equally clear that within group the increase in correlation in going from printer output to display output (Group II) far exceeds the increase in correlation in going from display output to printer output

(Group I) for both of these statistics.

The evidence from the Spearman and the Kendall tests definitely indicate better decision making under display device presentation. With this result we conclude the evaluation of the statistical results.

The economics of a system of display devices for decision making will not be explored here, however, it is evident that the very specialized research equipment used for this experiment is both expensive and unnecessarily elaborate for an operational system. The prices and characteristics of display equipment that will serve the purpose very well are frequently published.[19]

The minimum display unit for implementation of an information system of this general type should have alphanumeric display capabilities and a programmed function keyboard, or equivalent means of easy display selection. The size of the display face is crucial to the extent that it must be able to contain enough material to be of interest and still allow character size and spacing to enhance readability. For instance, the IBM 2250 used in this experiment has a display face twelve inches square with a maximum capability of fifty-two lines of seventy-four characters each. The information in the displays (Figures 6, 7, 8, 9) is rather densely packed and is digestable only by someone sitting in the console chair immediately

[19]Adams Associates, Computer Characteristics Quarterly, Second Quarter 1968 (Watertown, Massachusetts: Keydata and Adams Associates, Inc., 1968), pp. 179-187.

in front of the display face. A smaller display face
would mean that displays would have to be segmented; the
same information in smaller characters on a smaller display
face would be the wrong compromise. With segmented
displays, more programmed function keys would be needed and
in some ways the problem of how to ask for a particular
display becomes more complicated for the user. It is
unfortunate that the great majority of the pure alpha-
numeric display units have small display faces - eight
inches by six inches appears to be a popular size. Other
features of the IBM 2250, such as an alphanumeric type-
writer keyboard, line-drawing capability, and a light pen,
would serve only to detract from the simplicity and utility
of the system and add only to the cost of this application.

In addition to the display device proper, this
experiment used other system facilities. The display unit
had a self-contained buffer of 8,192 characters. Of this,
a maximum of 2,000 characters of buffer storage were used
at any one time. The display program in the main storage
of the IBM 360 Model 40 used approximately 13,000 characters
for program and 21,000 characters for tables. An additional
46,000 characters of disk storage were used for table
overlays.

How generalizable are the results of this experiment?
The display system evidently achieved the objective of
presenting a complex situation, which involved many inter-
relationships, in a manner such that the key concepts and

fundamental correlations were clearly understandable. The display system appeared to facilitate interpretation and extrapolation of the relevent data; a significant element in the decision process. The reduction of reaction time of top-level decision makers in this environment is both an interesting result and an important objective of any executive display system. While there is an obligation to report these results in relation to the experiment group itself, the composition of this group allows us to extend the results to a wider group of individuals. It would appear reasonable to apply the results to that class of individuals who are experienced in and actively making decisions in the inventory control field. It is tempting to extend these results to decision making in general; however, that extension will have to await further investigation and experimentation.

What direction should further work take? One point of great interest would be the exploration of the differential cost or savings of decisions using display units and printer output. This is a rather difficult area to define in that dollar values and weightings must be assigned not only to such elements as a reduction in inventory valuation and the cost of lost sales, but also to the generated purchase actions, availability of material, timeliness of decision, system cost and other influencing factors. The advantage of having such a differential cost at hand is obvious; just how to go about obtaining it is not.

Statistics on the frequency of use of the various displays should be collected, both automatically and by experimenter observation. The correlation of the frequency of use by display type with the individual's consistency of decision would be most important for the design of extensions of this system. Unfortunately, the importance of this statistic was not realized until this experiment was well under way.

Whatever the extension of the program, there should be the capability for the decider to request a hard copy of any display he wishes. If line drawing capability is used, this, of course, implies the availability of the equivalent of a line plotter for hard copy output. This requirement is more operational than experimental. We have no doubt as to the utility of such a feature for the decider in an operational environment, and if a display unit has a line drawing capability, it should be used with this requirement in mind.
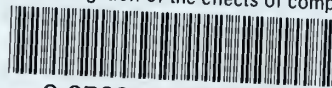
SELECTED BIBLIOGRAPHY

Adams Associates. Computer Characteristics Quarterly.
    Second Quarter. Watertown, Massachusetts: Keydata
    and Adams Associates, Inc., 1968.

Brown, Robert G. Statistical Forecasting for Inventory
    Control. New York: McGraw-Hill Book Company, 1959.

Burdick, Donald S., and Naylor, Thomas H. "Design of
    Computer Simulation Experiments for Industrial
    Systems," Communications of the ACM, 9 (May, 1966),
    329-339.

Cochran, William G., and Cox, Gertrude M. Experimental
    Designs. New York: John Wiley & Sons, Inc., 1962.

Hays, William L. Statistics for Psychologists. New York:
    Holt, Rinehart and Winston, 1963.

International Business Machines Corporation. IBM System/
    360 Operating System, Graphic Programming Services
    for IBM 2250 Display Unit, Form C27-6909-4.
    December, 1967.

_____. IBM System/360 Component Description, IBM 2250
    Display Unit Model 1, Form A27-2701-1. January 27,
    1967.

Luxenberg, H. R., and Kuehn, Rudolph L., eds. Display
    Systems Engineering. New York: McGraw-Hill Book
    Company, 1968.

Naylor, Thomas H.; Balintfy, Joseph L.; Burdick, Donald S.;
    and Kong, Chu. Computer Simulation Techniques.
    New York: John Wiley & Sons, Inc., 1966.

_____; Werth, Kenneth; and Wonnacott, Thomas H.
    Methods for Analyzing Data from Computer Simulation
    Experiments," Communications of the ACM, 10
    (November, 1967), 703-710.

Plossl, G. W., and Wight, O. W. Production and Inventory
    Control. Englewood Cliffs, N. J.: Prentice-Hall,
    Inc., 1967.

Sackman, H.; Erikson, W. J.; and Grant, E. E. "Exploratory Experimental Studies Comparing Online and Offline Programming Performance," Communications of the ACM, 11 (January, 1968), 3-11.

Steel, R. G. D., and Torrie, J. H. Principles and Procedures of Statistics. New York: McGraw-Hill Book Company, 1960.

Winer, B. J. Statistical Principles in Experimental Design. New York: McGraw-Hill Book Company, 1962.